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PASSIVE SOLAR HOME

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February, 1978

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OVERVIEW OF SOLAR/WOOD HOME HEATING PROJECT

Introduction

This report describes the passive solar/wood heating system constructed with the assistance of DNR & C through the Alternative Renewable Energy Sources Program under grant RAE 45-Fowlkes-014. This grant covered the time period between November 11, 1976 and December 12, 1977. The amount granted was $10,000.

The house and solar/wood system are in operation and the house has been occupied since 1 September 1977. All of the $10,000 granted was used and the grantee spent about $3,000 additional, plus labor. The system works and no major problems are anticipated.

Budget

Figure 1 shows a breakdown of the expenses into the budget categories contained in the original proposal. The expenses are also itemized by request number. Also shown is a record of the amounts requested and the amounts received in each request during last year. A file of invoices substantiating these expenses is on record in our office.

There were additional expenses which are not itemized here since the grant funds were already exhausted. These expenses were mostly labor in all categories and materials involved with construction increments. For your reference the total cost of the project was about $13,000.

Expenditures broken down into grant request periods

Budget category	Amount granted	#1	#2	#3 (corrected)	* #4 + #5 + final	Total	Surplus
Solar wall	$3000	0	75.30	0	3439.89	3515.19	(-515.19)
Solar window	3515	0	431.43	2509.84	1673.33	4614.60	(-1099.60)
Water heater	260	0	0	108.00	176.66	284.66	(-24.66)
Wood system	1800	0	104.80	155.00	1442.53	**1702.33	97.67
Construction increments	1425	802.80	425.50	0	0	**1228.30	196.70
TOTALS	$10,000	802.80	1037.03	2772.04	6732.41	11,345.08	(-1345.08)

* The fourth and fifth requests included advances. Therefore, they are itemized here along with the final period.

** The surplus funds in these two categories are transferred to to the solar wall as allowed by the contract.

	Request	Received	10% withheld
#1	802.80	722.52	80.28
#2	1037.03	1037.03	
#3	3068.29	3068.29	
#4	2500.00	2500.00	
#5	2591.88	1672.16	919.72
TOTAL		9000.00	1000.00

Figure 1: Record of expenses

DESCRIPTION OF THE SOLAR SYSTEMS AND THE AUXILIARY HEATING SYSTEMS

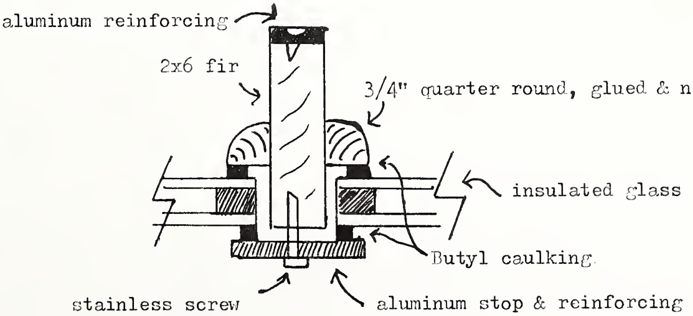
Solar Window

The solar window faces due south and is vertical. The total south-facing glass area of the house is 582 ft^2. Of this area, 480 ft^2 is backed with a heat storage wall and the remaining 102 ft^2 is a simple passive collector.

The window is double-glazed with 1/8" tempered Herculite K having a 5/8" air space. The air space, as well as the windows themselves, are sealed around the perimeter with butyl rubber. The solar energy transmittance of the window is 75% for normal incidence. The windows came from Better Buys (Nebraska) through a local dealer, Livingston Glass.

The foundation for the solar window is integrated with the solar wall. It is basically a reinforced concrete box-beam. The rigidity afforded by this construction should reduce the chances of breakage of the solar window panels due to settling.

The windows are mounted in frames, or mullions, which were fabricated on-site. Commercial aluminum mullions cost $5 to $10 per foot and many do not have a thermal break. The mullion design used in my house is shown in the sketch below. A construction photograph of the solar window frame is shown in Figure 2.



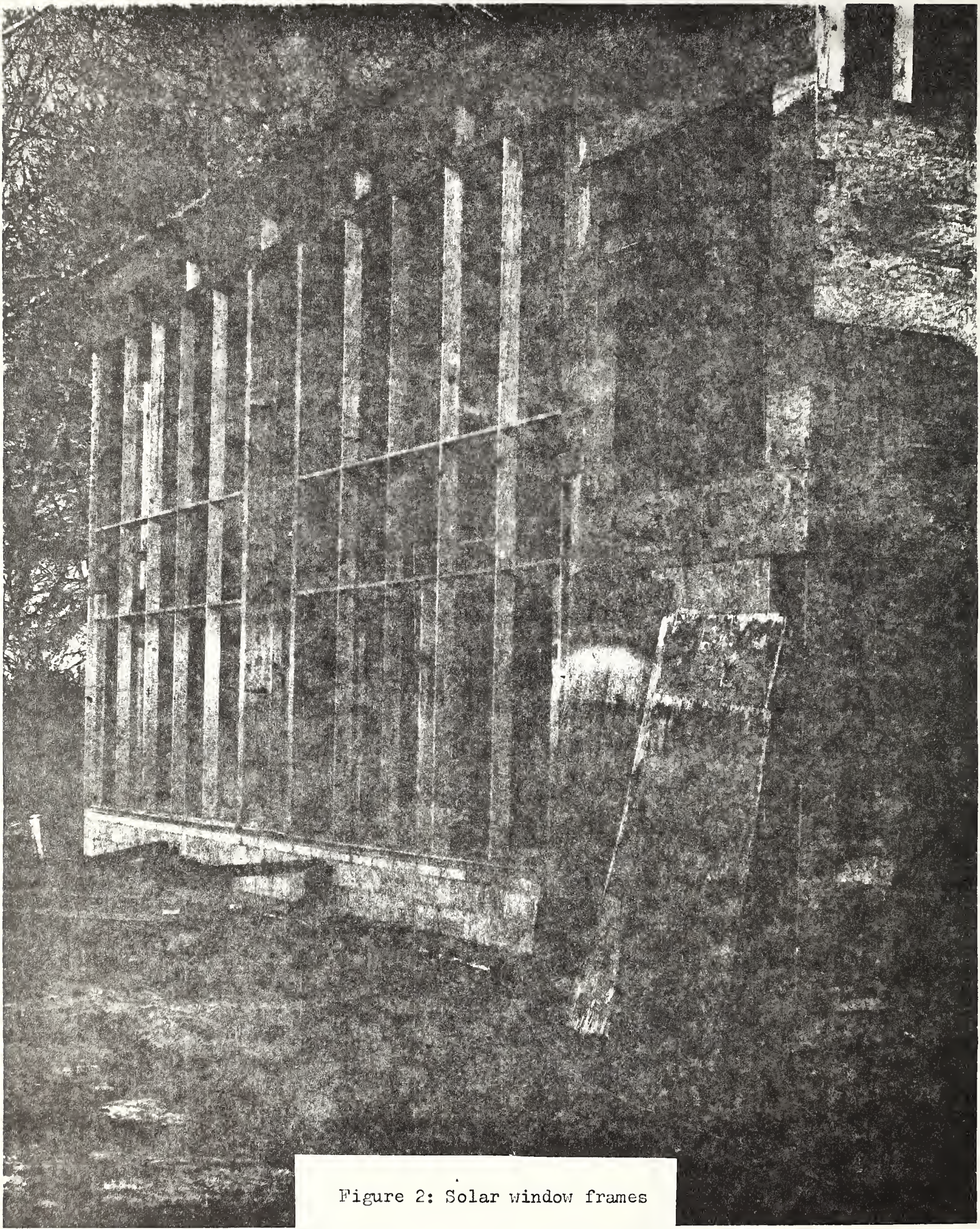


Figure 2: Solar window frames

The materials cost for this construction is approximately

	$/foot
aluminum	1.50
stops	.20
mullion	.30
screws	.15
Total	2.15

The aluminum was chosen for its non-corrosive properties. Metal strapping is required to meet the 25 psf design wind load required by the building codes. The strapping was supplied by Weissman & Sons.

Solar Storage Wall

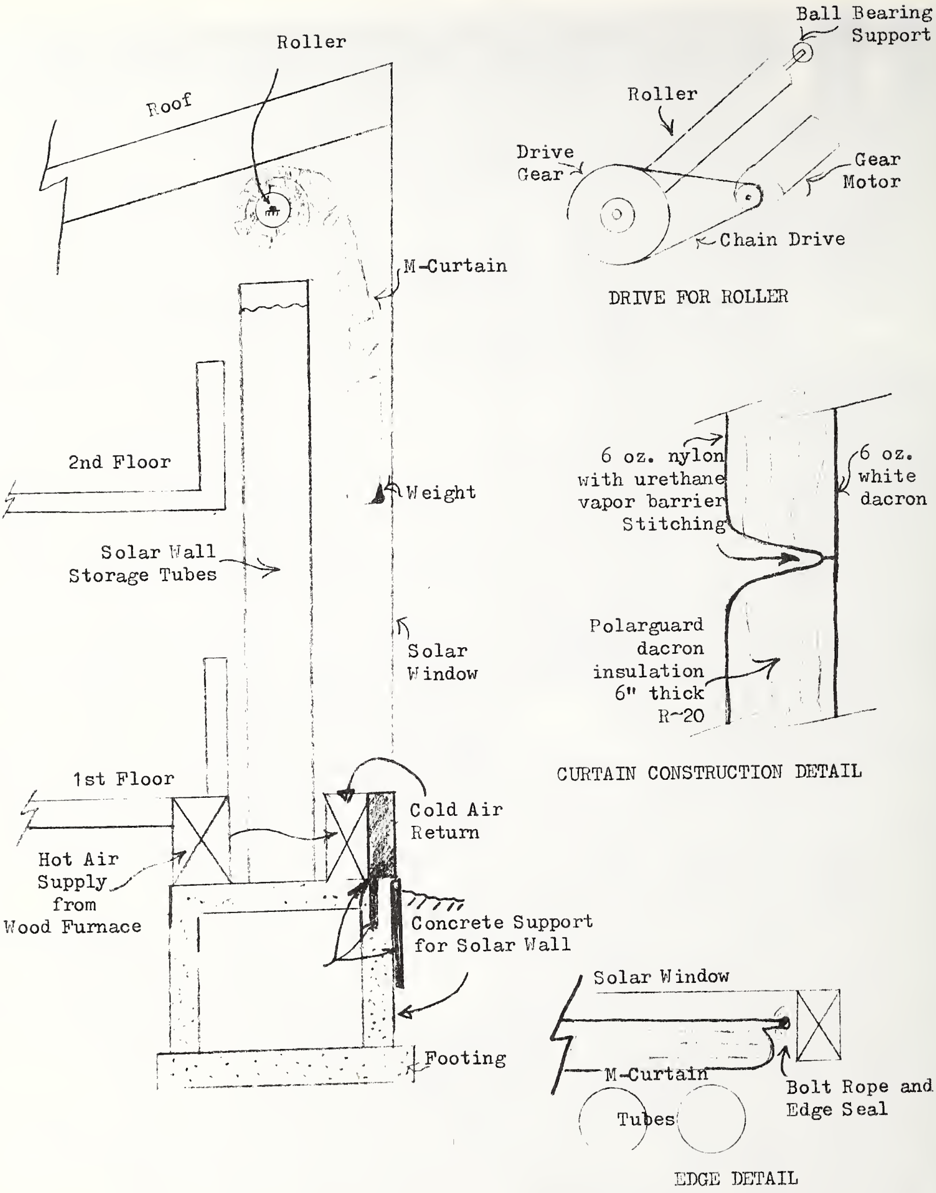
The foundation for the storage wall is shown in the schematic drawing in Figure 3 . The footing is 5' x 36' in plan and averages over 8" thick. It is reinforced with ½" reinforcing bar arranged in a mesh tied with wire on 1 foot centers, Figure 4.

The inner and outer foundation walls are 8" thick by 45" high and contain 2 rounds of ½" re-bar with extra re-bar added as ties in the corners and at the juncture with the footing. There are access holes through the inner wall for use as a plenum chamber for the heat exchanger.

The upper slab joining the inner and outer walls has an average thickness of 7" and has one access hole in the center 20" x 24". The slab contains ½" re-bar mesh tied on 1 foot centers. The transverse re-bar were cast into the vertical walls to securely tie the slab to the walls.

The footing, walls, and slab form a reinforced concrete box beam. This structure is very strong and rigid. It supports the solar window, the water storage wall (~ 32,000#), and the front of the house.

The bearing stress under the footing is 1500 psi. The soil was tested prior to construction and was rated for 3000 psi giving a factor of safety of 2. The combination of an adequate footing and a rigid beam should guard against settling and bending of the house and window due to the weight



DRIVE FOR ROLLER

CURTAIN CONSTRUCTION DETAIL

EDGE DETAIL

Figure 3: SCHEMATIC OF M-CURTAIN SYSTEM

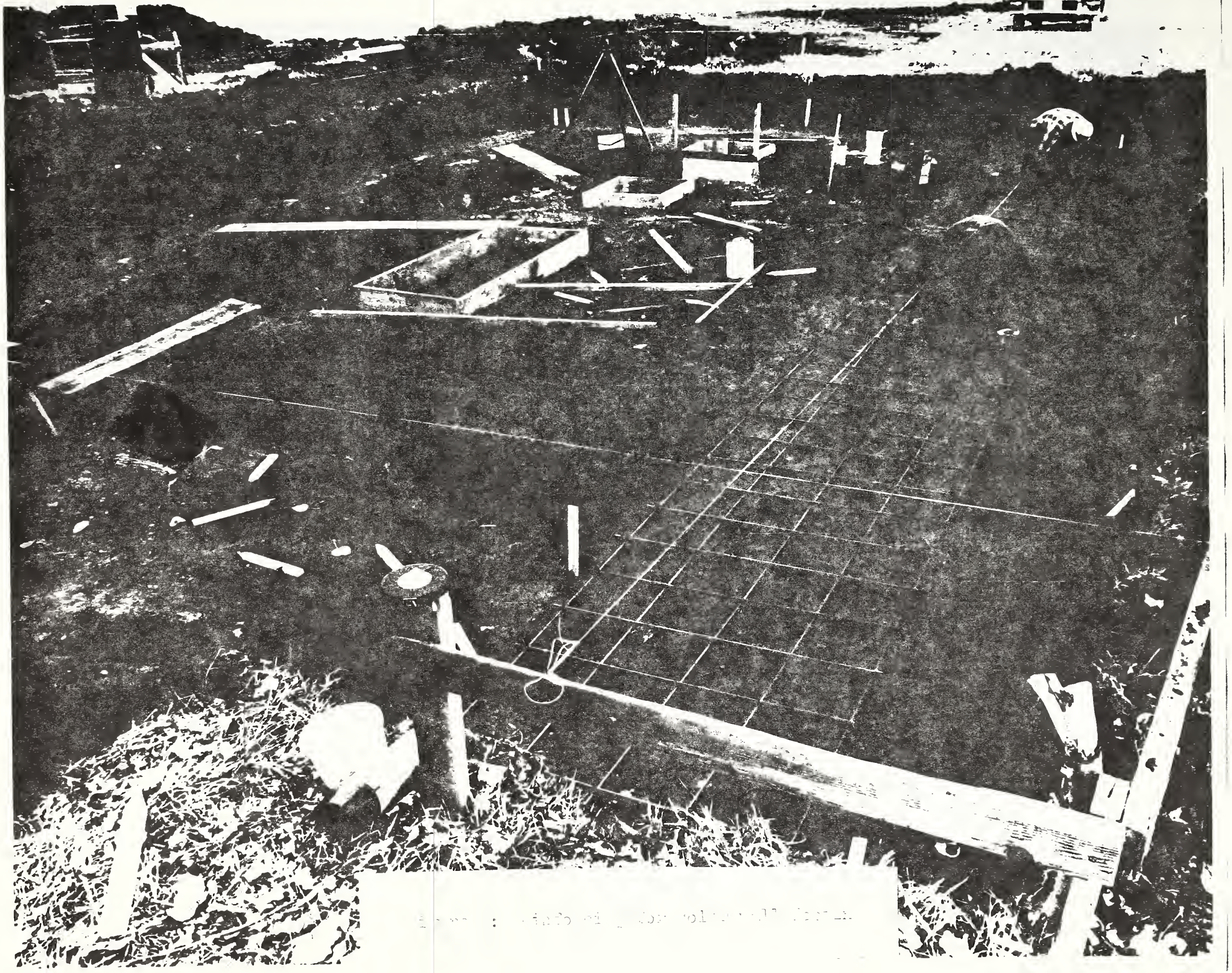


Figure : [illegible]

of the storage wall.

Heat loss through the concrete base is controlled with a 1" polyurethane foam thermal break along the edge of the slab and 2" of polystyrene along the outside of the outer wall. (See Figure 3.)

Storage Wall

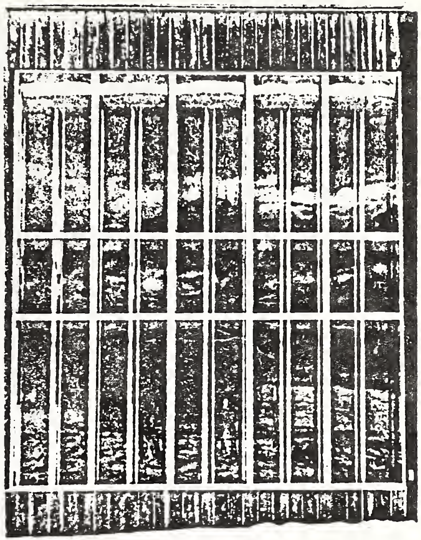
Thermal storage is provided by 20 tubes, 16" in diameter and 17' long. These tubes are filled with water having a total weight of about 30,000#. The heat storage capacity is thus 30,000 BTU/°F temperature change. The total heat storage capacity is well over 1,000,000 BTU, which is equivalent to three average days' heat requirement in January in Bozeman, Figure 5.

The tubes were made by Spunstrand in Wallace, Idaho. They were fabricated on a filament winding machine and have a wall thickness of 1/8" nominal. Bottoms and tops were molded onto the tubes and a 2" access hole in the top allows the tubes to be filled with water. The empty tubes weigh about 80 pounds each. The cost was about $170 per tube with shipping.

When the tubes are filled with water, the static pressure at the bottom of the tube is about 8 psi. The hoop stress in the tank is thus about 500 psi, which is well within the allowable load for this material. The large factor of safety allows for possible unexpected loads due to handling, stress concentration, and earthquakes.

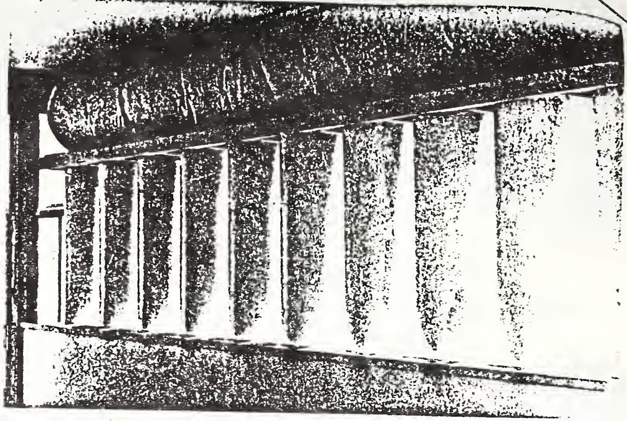
The degradation of the fiberglass due to the water inside the tanks should be negligible over a life of 30 years. The ultraviolet degradation of the exposed surface should also be negligible. The material will withstand temperatures of about 250°F, which is at least 100°F above the anticipated operating temperatures. The part of the tubes facing the window are painted with a flat black/green enamel to increase the solar absorption.

The tubes are insulated from the concrete support beam by a floor liner consisting of 5/8" particle board resting on 1" closed cell styrofoam. The

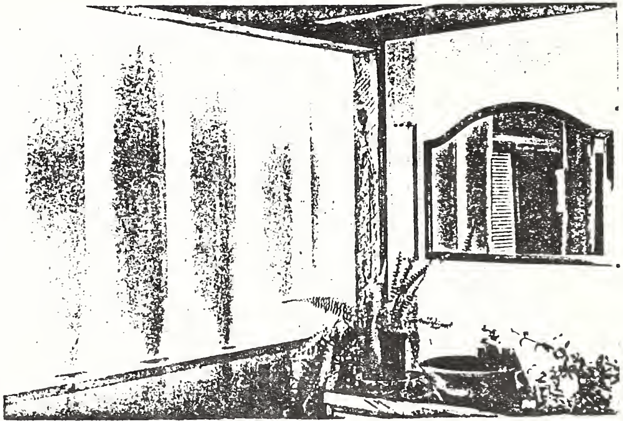


Solar window from outside showing tubes, aluminum mullions, solar window and furled insulating curtain. This photo shows only one bank of 10 tubes, there are a total of 20 tubes or two banks in the system.

Figure 5: Photographs of the storage wall, consisting of fiberglass tubes filled with water, viewed from both outside and inside.



Fiberglass tubes forming solar wall as seen from upper floor; note rolled insulating curtain at top of photo.



Solar wall as seen from lower floor dressing room.

tubes are filled, leaving a small space at the top to allow for expansion. The opening is then plugged.

Insulating Curtain

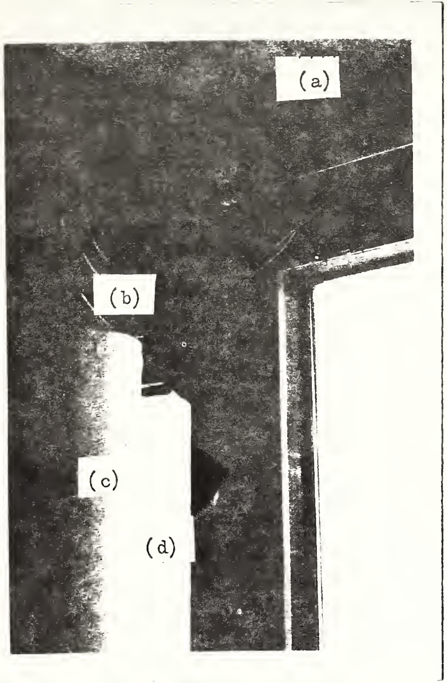
One of the more unique and important elements of this system is the movable insulating curtain. The calculations in the original proposal showed that a normal, uninsulated, Thrombe wall passive system would not work in Montana's winter climate. The curtain must have a high insulating value (about R-20) and must be durable so that it will last through at least 10,000 cycles of operation over its 30 year life.

The construction and method of deployment of the curtain is shown in Figure 3 . It works basically like a large window shade. The roller is driven by a 1/3 hp reversible gear motor (Dayton 7Z135), 30 rpm, through a number 50 roller chain having a speed reduction of about 5X. When the motor is turned on, the curtain will roll or unroll in about one minute. Limit switches protect the mechanism.

This motor will eventually be automatically controlled by a sensor so that it will raise the curtain when the sun shines on the wall and lower the curtain if the sun is obscured for more than 20 minutes. The system is currently being operated manually until it has been thoroughly tested.

Each roller is a 6" diameter 12 gauge steel tube 15 feet long. It is supported by stub shafts on each end which are carried in roller bearings. (See Figure 3 .) The curtain is bolted to the tube through ¼" grommets spaced each 2' along its upper edge. The edges of the curtain have a 3/8" bolt rope or "welting". This bolt rope runs in a plastic guide made by slitting 3/4" diameter plastic tube. This edge configuration serves as a track to restrain and guide the curtain and provides a seal to minimize heat loss by convection around the edges.

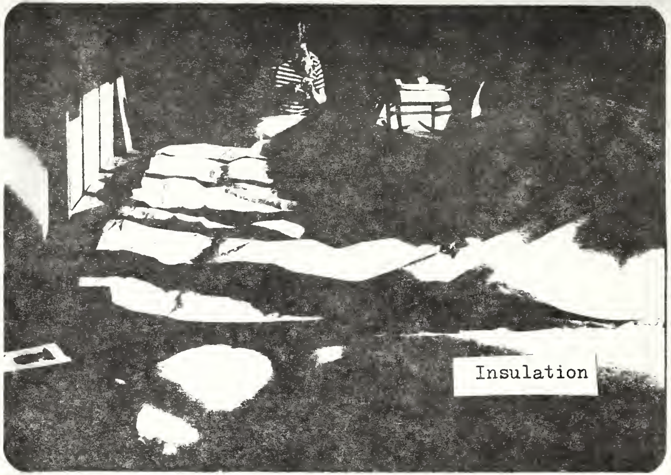
The outside of the curtain is fabricated of 6 oz. white dacron sailcloth. The panels are arranged vertically for strength. The seams are double



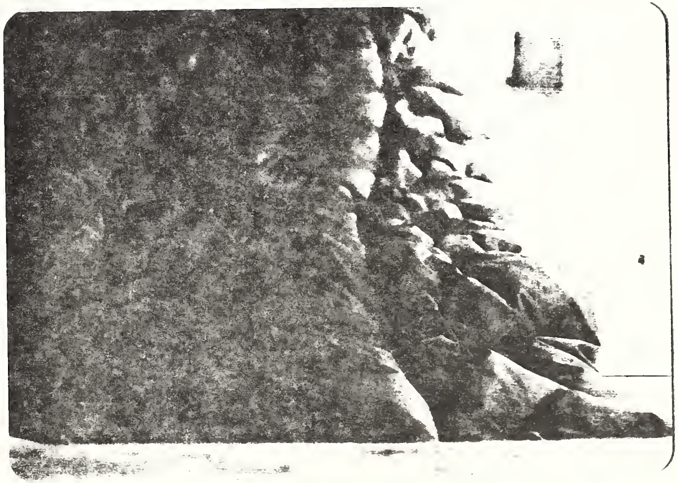
Insulating curtain installed and furled

(a) Drive motor
(b) Insulating curtain on roller
(c) Fiberglass storage tube
(d) Solar window

Figure 6: Photographs of insulating curtain and roller system



Installing insulation in curtain; Polarguard insulation in foreground; white Dacron faces window



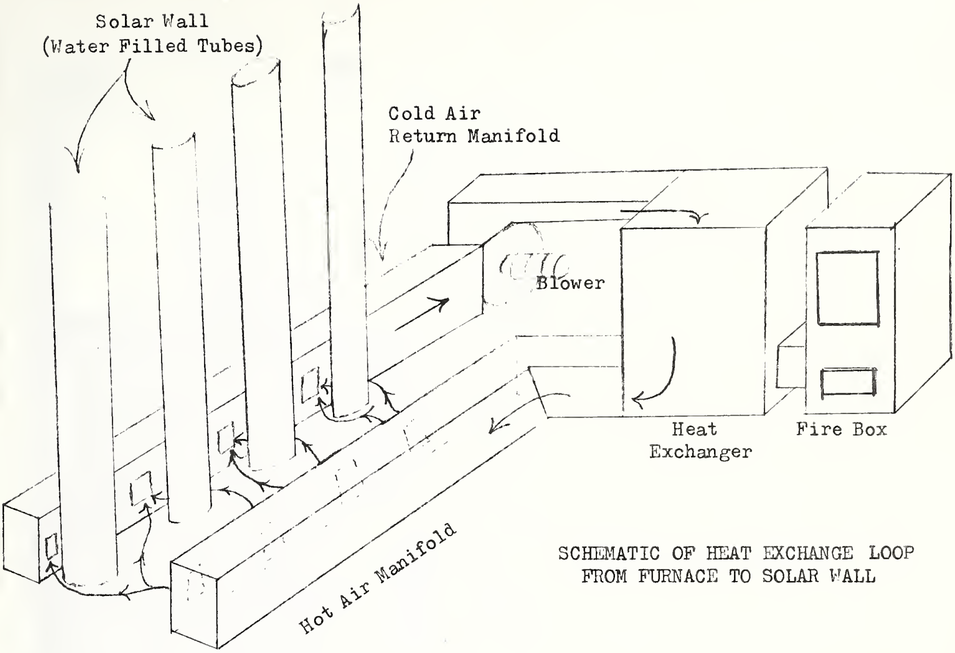
Inside of curtain showing nylon insulation pockets stitched with dacron thread. The inside of the curtain is made of 6 oz. nylon "pack cloth". This material is abrasion resistant and has a urethane "waterproof" coating which will serve as a vapor barrier protecting the insulation from moisture build-up.

The insulation itself is about 6" thick and consists of 4 layers of 10 oz. Polarguard (a continuous polyester fiber). This material is widely used in sleeping bags and clothing. Its main features include a low thermal conductivity, high compressability, and good recovery from compression. The Polarguard insulation bats are held in place by loose dacron "quilting" on 2' centers.

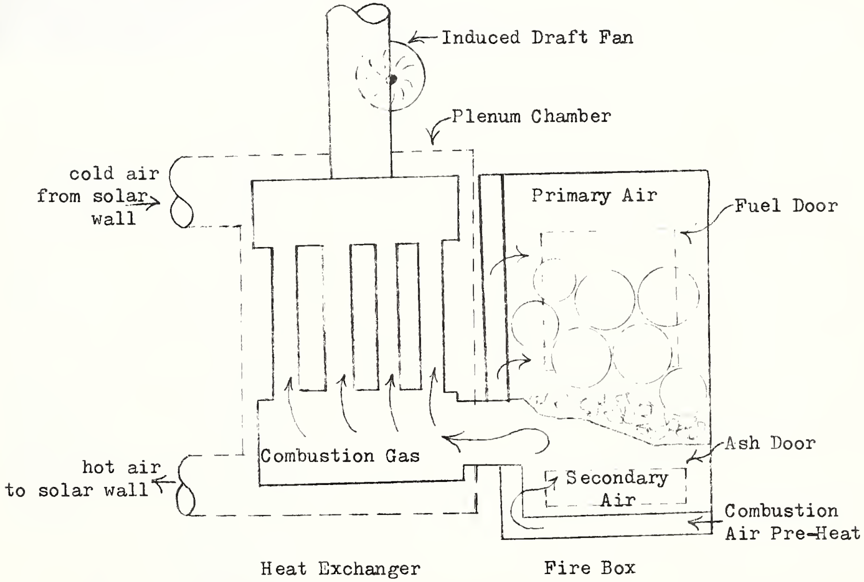
The curtain is compressed as it is rolled up into a volume which is about 40% of its free volume. The original proposal showed the curtain being stored overhead rather than rolled. The overhead storage would have required the construction of a false ceiling and a more complicated raising mechanism. The roller system was judged to be a far superior, as well as, more economical concept. See photographs in Figure 6.

Wood Auxiliary Heat

The original wood heating design was a large wood burning furnace and heat exchanger, Figure 7. Test showed an overall average conversion efficiency of 58%, which is quite good. However, due to the excellent performance of the solar system the furnace proved to be oversized by a factor of about 3. It has since been replaced by a small cast iron wood stove, which is more appropriate. On an annual basis the house uses 1 to 1 1/3 cords of pine each year for backup heat.



SCHEMATIC OF HEAT EXCHANGE LOOP
FROM FURNACE TO SOLAR WALL



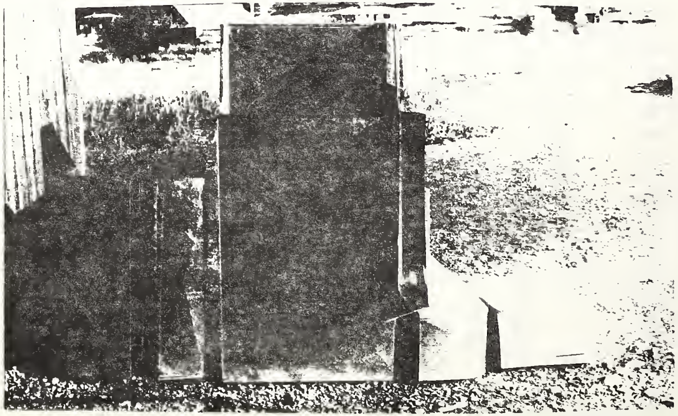
SCHEMATIC DRAWING OF FURNACE SYSTEM

Figure 7: Furnace & heat exchanger

Photograph of cold air return duct along the base of the solar window before installation of the fiberglass tubes. The hot air duct is hidden in this photograph but runs along the base of the tubes on the right hand side.

Figure 8: Photographs of the wood furnace and the heat exchanger loop which takes the heat from the furnace to the solar wall. Refer to the schematic drawing in Figure 7.

Wood furnace; fire box and heat exchanger before the installation of sheet metal plenum chamber. The fire box on the right has a fuel door and an ash door. The heat exchanger has an upper and lower inspection plate.



Sheet metal enclosure which encloses furnace and heat exchanger.

PERFORMANCE

Overheating

One of the most frequently asked questions by people who are visiting the demonstration house conserns the overheating problem during the summer. The original proposal included estimations of the solar insolation on a monthly basis on the vertical collector. These estimates show that the summer insolation is much less than the winter insolation. This is due to the location of the sun. In the summer the sun rises and sets to the north of an east-west line. This means that the sun strikes the vertical south-facing surface only during the middle part of the day,, approximately 9:30 to 3:00. Also during the middle of the day the sun is high in the sky at an angle of over 60°. The effective area of the collector is maximum at noon and is approximately Cos 60° or about 50% of its actual area. This radiation is at a low grazing angle which results in a greater amount being reflected from the glazing. All of these factors tend to drastically reduce the available radiation received by the solar window.

During the summer we were working on the house during many sunny days when the outdoor temperature was near 80°F. The storage wall was not installed so that the full radiation came directly into the house. From this experience it was our impression that there will be no serious problem with overheating during the summer. It is anticipated that with the solar wall in place the summer radiation will be just about exactly the amount needed to keep the house warm during the evening. We think that the insulating curtain will probably be permanently left in the "up" position during the summer. The system will thus operate about like a **Thrombe** wall during the mild season.

During September and October we were living in the house but the storage wall was not installed. The sun during these months was more to the south and lower in the sky so that the insolation on the solar window was considerably greater. We did experience overheating during these months. On clear days, if the house was closed up, the temperature would get up to 90-100°F by 5:00 p.m. By the next morning the house temperature would be down to 50-60° F. It seems probable that if the storage wall had been in position during this part of the year we would have been 100% solar heated with temperature swings of only 10-15°F.

Early Test

During November we experienced some cold weather with temperatures going to 28°F. below one night. During this period the insulating curtain was essentially operational but the storage wall had not been installed. The wood back-up furnace was also being "worked on" so that it was not in operation. The only sources of auxiliary heat were a Franklin stove and a wood heater located in the shop area attached to the house. On several mornings during this cold spell the house temperature got down to about 45°F. This was the minimum temperature and attests to the value of energy-conserving features incorporated into the design and construction of the house.

During this cold spell there was only one day that had a significant solar insolation. The outside temperature on that day reached a high of about 12°F. The insulating curtains were removed and by afternoon the inside temperature of the house was 82°F. during the afternoon and early evening. It was reassuring proof that useful heat could be collected even during extreme cold periods. It was also reassuring to prove that the heat load of the house is quite low.

During the two week period around Christmas half of the storage wall was in place. There were several sunny days and the back-up wood system was only used twice. During a two week period in early February with the solar wall 90% filled we were 100% solar.

Our largest utility bill (electricity) has been about $20. This includes cooking and 100% water heating. When the pre-heat tank is connected this should be reduced significantly.

Future Performance

If the Department requests, I will plan to write a brief Addendum to this report at the end of next year. Included in this Addendum will be an informal discussion of our experience with the system during the year. Special note will be made of outstanding strong points and weak points of the design.

DEMONSTRATION INSPECTIONS

During the last year (1976-77) we have had over 200 people through the house for the purpose of demonstration. We have kept a log book which records many of the names and addresses of the visitors. Visitors have come from California, Oregon, Washington, Texas, Alabama and Ohio. Backgrounds of the people include a professor who teaches solar energy and is writing a textbook on solar, architects and engineers, builders and contractors, artists and photographers, lots of casual "lookers", and even a Girl Scout Troop.

I have given special tours to a group of contractors who were at the University studying advanced building methods, the League of Women Voters, and an informal Solar Energy class from MSU. I have given lectures and presentations concerning the design of the house to an engineering Energy class at MSU, the Montana Academy of Sciences at Missoula, an adult education class at MSU, a solar meeting held by Max Baucus, and a continuing education class of solar enthusiasts at MSU. Several other talks and organized tours are scheduled during February.

We have had requests for information on the house from the National Solar Heating and Cooling Information Center in Rockville, Md. The house is currently listed in their file of solar homes in the United States. The editor of Alternative Sources of Energy visited the house and expressed interest in doing an article. W.A. Surcliff, author of "Solar Heated Buildings: A Brief Survey" has requested details on the house and the insulating curtain for inclusion in future publications. A photography student from MSU did a photo documentary on the early stages of the construction of the house as a class project, which photos were displayed at MSU last spring. The Bozeman Daily Chronicle has carried a photo and story about the house.

The information herewith is given as evidence that I have been satisfying the terms of the demonstration agreement with DNR&C during the last year.

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